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A Decision Support System for Freight Transportation Planning

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ABSTRACT

This paper examines the structure and components of a Decision Support System designed to assist the tactical planning of activities of an intercity multimode multicommodity freight transportation system, using the tactical planning of LTL motor–carrier operations as an example. In particular, such a computer–based planning system has to combine a "local" data base, together with procedures to access and analyze it, interfaces with the management information system of the company, problem modeling and scenario defining facilities, optimization algorithms and post–optimal procedures and, interactive–graphic capabilities to display and help analyze data and results.

KEY WORDS: DECISION SUPPORT SYSTEMS
INTERCITY FREIGHT TRANSPORTATION,
INTERACTIVE–GRAPHIC SYSTEMS,
TACTICAL/STRATEGIC PLANNING.

RESUME

Dans cet article nous examinons la structure et les composantes d'un système d'aide à la décision traitant le problème de la planification tactique des réseaux de transport interurbain de marchandises. Le transport routier de charges partielles est utilisé à titre d'exemple. Un tel système d'aide à la décision comprend, en particulier, une base de données locale et des procédures d'accès, des interfaces avec le système d'information de l'entreprise, des outils de modélisation et de définition des scénarios, des procédures d'optimisation et d'analyse post–optimale et finalement, des interfaces interactives–graphiques permettant d'inspecter les données et les résultats.

MOTS CLES: SYSTEMES D'AIDE A LA DECISION
TRANSPORT INTERURBAIN DE MARCHANDISES,
SYSTEMES INTERACTIFS–GRAPHIQUES,
PLANIFICATION TACTIQUE/STRATEGIQUE.

I. INTRODUCTION

Freight transportation plays an important role in the North-American economy. In the United States, for example, it generates revenues which represent close to 10% of the GNP. During the last decade, the environment of the freight transportation industry has become much more competitive. As a result, transportation services are now more sophisticated and service levels more selective than before, thereby increasing the need for better operations management in this industry.

Organizations which both supply (or regulate) multimodal freight transportation services and which control, at least partially, the routing of goods constitute an important segment of the transportation industry. This group includes transportation systems such as freight transportation by rail with different rail services, the "less-than-truckload" (LTL) component of intercity motor-carrier freight transportation, air freight services, freight transportation services in developing countries where a central authority controls (more or less) the entire transportation system, courier and postal services, and container and intermodal transportation.

To control the activities of a freight transportation organization and to make the best possible use of the system's resources, several policies have to be defined and implemented. These policies and the associated modeling problems are generally classified into three groups corresponding to the widely used three *planning levels*: strategic, tactical and operational [5]. It is utopian to think that one model may integrate all the aspects of one of these transportation systems, or those of its corresponding planning process. In particular, the hierarchical (vertical) relations which may be observed amongst the three levels of planning greatly contribute to the impracticability of formulating a unique model for the whole transportation system and emphasizes the need for different formulations addressing specific planning problems [5]. Furthermore, no model can represent all written regulations nor all unwritten rules and traditions that usually affect the operations of such organizations. One could, of course, add more constraints and details to an existing model to try to circumvent these problems and to reflect more closely the reality, but would have to accept the inevitable loss of model flexibility and algorithmic efficiency. This emphasizes the need for planning tools where the user may not only manipulate data and results but may also adjust the model to its own reality.

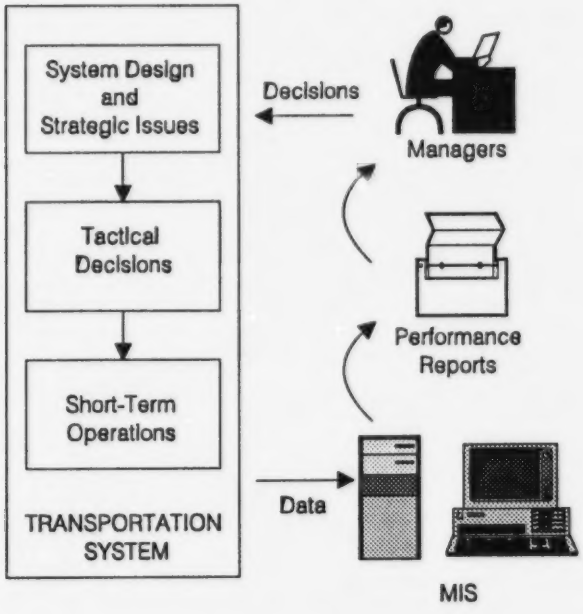
The objective of this paper is to examine the components of a Decision Support System (DSS) designed to assist the tactical planning of activities of an intercity multimode multicommodity freight transportation system. The next section introduces and discusses the role of DSS in the management of transportation systems. Then, after a brief description of the network tactical planning problem, we present and discuss the structure and major components of a comprehensive DSS, some of which are still in development. Note that, in order to clarify the presentation and to allow for a more immediate identification of the issues and solutions mentioned, we shall use the tactical planning of LTL motor-carrier operations as an example throughout this paper.

II. MANAGING THE TRANSPORTATION SYSTEM

Transportation systems are complex organizations, where important resources have to be allocated and organized, while considering interrelated objectives of economic performance and quality of service. A large volume of very diverse data have to be considered in any decision making context. Therefore, a comprehensive and efficient Management Information System (MIS) is required in order to assist management in performing its tasks.

A typical transportation system planning and control cycle using an MIS is sketched in Figure 1. Data is collected from the transportation system and, condensed into statistics and performance reports, it is fed-back to managers, in order to assist making decisions that hopefully will improve or maintain the system performance.

FIGURE 1
Managing a Transportation System with a MIS



In the past fifteen years or so, most major North-American motor-carriers have adopted the process described in Figure 1. It is interactive in that managers are reacting to the information by making decisions whose effects will not be known for some time. This situation has

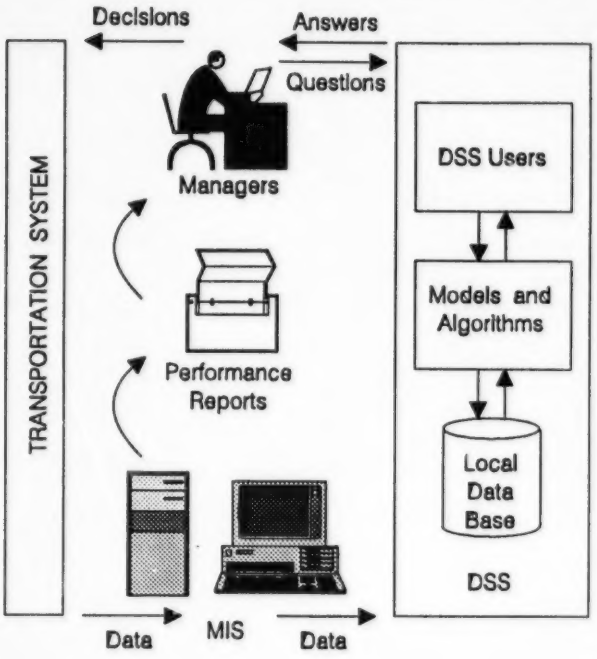
improved recently with the advent of more sophisticated, rapid and user-friendly computerized information systems for managers. These systems are sometimes referred to as Executive Support Systems (ESS), as they enable managers to obtain the information they require more rapidly and in a friendly environment (tables, graphics), and to perform some data analysis functions, such as identifying areas of unsatisfactory performance. In particular, these systems may assist managers in troubleshooting functions by displaying more detailed information, as required, directly on the screen [8]. However, neither the MIS, nor these ESS provide managers with answers to the many "what-if?" questions they ask about their transportation system. This is where Decision Support Systems come into play.

According to Geoffrion [9], a DSS (or Management Support System) is made up of the following elements: *(i)* a *data file* written in computer readable form; *(ii)* a *model* describing the real system studied and the relations which may influence its performance; *(iii)* a *solver*, or computer program for solving the model with various commands (simulation or optimization); *(iv)* an *interface*: a facility for communication between the above elements and the system users and managers.

A DSS (Figure 2) allows managers evaluate different solution alternatives to problems identified in the performance reports (simulation function), or yet find the best solution to a particular problem (optimization function). With respect to this role, one of DSS's most fundamental characteristic is that it offers the manager a ready-to-use analysis environment, where models and methods are already developed and finely tuned to the company's operations and MIS. Thus, a DSS preempts, in most cases, the need to develop ad-hoc analysis tools, and the associated delays and costs, and offers the capability to rapidly provide managers with efficient answers to their questions. This characteristic is illustrated in the following examples.

A typical tactical planning issue is concerned with the question *what if a new service is introduced?*: "A large trucking company is experiencing difficulties in providing its customers with reliable service between two points in its network. The manager wants to evaluate the consequences in terms of both costs and on time performance of introducing a new (more reliable) transportation service between those two points. The issue is how to measure the impact this new service will have on the whole network. Indeed, this new service may attract

FIGURE 2
Managing a Transportation System with a DSS



additional traffic that was previously using alternate routes in the network."

This manager may never obtain a proper answer to his question (and this is based on real life experience) unless he can rely on the existence of a tactical planning DSS such as the one proposed in this paper. With a DSS, the new transportation service and its characteristics will simply be added to the company's service network data file. This new data will be used as input to a network optimization model that will produce a revised transportation plan showing the attractiveness of both the existing and the new transportation services, the service performance for each individual market in the network and the revised total cost of the system. With this information, staff analysts will be able to provide the company manager with both rapid and effective answers to his questions.

Strategic planning is often concerned with the *what if the network configuration is changed?* issue: "A motor-carrier wishes to evaluate the impact of adding a new breakbulk terminal to its network. This new facility is planned to be significantly more efficient than existing ones in its area: productivity is increased by forty percent and turnaround time is

drastically reduced for traffic being transported through that location."

Again, our DSS for tactical planning will provide some valuable answers by measuring the impact of such a network modification on the amount of freight handled at both the new and existing locations and consequently on the routing of freight through the modified network. It will also quantify the resulting improvements in operation costs and service performance, and offer managers a visual representation of both the general system statistics and the network operations. Additional analyses can also be performed to evaluate the sensitivity of the solution to various productivity improvement measures, and the impact this new terminal will have on the network balance between the number of trucks leaving and arriving at each terminal. Results of similar analyses performed on real life data are reported in [11] and [12].

Our DSS does not perform facility location analysis. It does, however, evaluate the network-wide impact of modifying the configuration of a transportation network. It will then be up to the manager to use this information, along with other data such as the fixed costs related to the location of the new breakbulk facility, to complete his financial analysis at the strategic level.

In order to provide rapid and adequate answers to the managers' questions, it may be necessary to integrate such decision support activities as industrial engineering, operations research and information management, into an organized system. It is therefore useful to distinguish between managers and DSS users. The latter may sometimes act as effective intermediaries between the former and the various elements of the DSS. Indeed, the very nature of decision support systems, with their models and algorithms, makes it difficult to design interfaces for managers who are not always willing to become familiar enough with such systems in order to use them effectively. They may prefer to ask their questions to staff members who will then be the real DSS users for whom adequate interfaces will be designed.

III. THE COMPONENTS OF THE PROPOSED DSS

This section is dedicated to the presentation of the main characteristics and components of the Decision Support System that we propose for the tactical planning of interurban multimodal multicommodity transportation carriers. But first, a brief description of the tactical planning problem.

3.1 The Network Tactical Planning Problem

In the LTL motor-carrier industry, tactical planning is usually performed over a period of a few months, in order to adjust the operations of the carrier to, for example, seasonal variations in the forecast demand. One of the main outputs of tactical planning consists of a series of rules and policies that affect the whole system and that often are collected in a *transportation (load) plan*.

According to Powell [10], the LTL load planning problem is the specification of how freight should be consolidated and routed over the network, given a set of services between terminals, to minimize the total transportation and handling costs, while improving, or at least maintaining, preset service objectives. To build a load plan, one must therefore consider the following interrelated problems: *Service Network Design*, the selection of the routes on which carrier services will be offered, as well as the determination of the operational characteristics and number of departures, per planning period, of each service; *Terminal Policies*, the general rules that specify for each terminal how freight and vehicles are to be consolidated, sorted and grouped; *Traffic Routing*, the determination of the itineraries on which to move the freight of each origin-destination pair; *Empty Vehicle Management*, the distribution of empty vehicles to satisfy demand and to rectify imbalances in the vehicle availability due to uneven traffic.

The construction of a good transportation plan is a complex task, as illustrated in the following example. Let us suppose that the demand for LTL transportation for a given market is expected to increase in the coming months. One could then increase the number of trailer departures, which would tend to increase transportation costs, while maintaining current service and reliability levels. On the other hand, one could also decide to maintain the number of departures and forward the additional traffic through intermediate terminals in order to maximize the utilization of trailer equipment. This would increase freight handling costs,

total transit times and terminal congestion which in turn could affect service reliability. These strong ties amongst the various aspects of the problem, as well as the inherent trade-offs between service quality and costs, illustrate the large number of possible operating strategies and the complexity of the decision process, and thus justify the use of integrated optimization-based planning models.

We propose a DSS, called TACTIC, which may assist transportation managers deal efficiently with these network tactical planning problems. Specifically, TACTIC offers the decision maker the possibility to address the problem globally, network-wide, to adjust the model to his problem, to visualize data, to efficiently generate, evaluate and compare a large number of global operating strategies, and to manipulate a solution until it meets all the unwritten rules and criteria. It is a stand-alone computer system, easy to use, that may efficiently run on the current generation of microcomputers and working stations. While each of these properties may appear in some systems, at our knowledge, they do not characterize any existing system for the strategic/tactical planning of operations for intercity freight carriers. Further details on intercity freight transportation and tactical planning issues, as well as reviews of the models and tools available to assist carriers with their various planning tasks, may be found in [1] and [7].

3.2 The Data

The data required to adequately represent a transportation system and its operations and, therefore, to build and to analyze a tactical load plan, fall into three main categories: *networks, matrices* and *functions*.

The basic transportation infrastructure that spans the problem under study is represented by a *physical network* made of *nodes*, associated to terminals, and *links* which define the physical connections between terminals. Nodes and links have a unique identifier, a type (e.g. break-bulk or end-of-line terminal), physical or operational characteristics (e.g. capacities or unit costs), while also providing space to store user data.

Freight is transported by vehicles that move according to a *service network*. Specifically, each service is characterized by the route it follows through the physical network from its origin to its destination, by the sequence of terminals where it stops on this route (if any), its

type (mode, speed-priority, etc.) and by some performance measures in terms of service targets, delays or reliability. Various physical or operational characteristics, as well as space for user data, are also part of a service description. The *frequency* is the other important service descriptor: it defines the level of service that is to be offered on the service route during the planning period.

Transportation demand is specified in terms of freight tonnage (number of vehicles), of a given commodity, to be moved from an origin node to a destination node. The triplet (origin, destination, commodity) defines a *market (traffic-class)*. The set of all markets for a given commodity, is called a *matrix*. Associated to each market are some meaningful data such as unit delay costs, minimum required level of service, user data, etc.

Freight flows are represented by using itineraries. An *itinerary* is a feasible journey for the freight of a given market: its origin, destination, sequence of intermediate terminals where work is done on freight (if any), and the service paths connecting these terminals. Each itinerary is characterized by the amount of flow moved on it and associated performance measures (costs, delays, etc.).

Functions link the various physical and operational characteristics of the system's components to the current level of activity on the network, in order to compute a number of performance measures in terms of operating and delay costs, reliability, respect of service objectives, etc. These functions make up the generalized system cost which is used as an objective function to the tactical optimization model described in Section 3.4.

A *scenario* is a complete set of network data, nodes, links, services, to which one associates a particular model formulation (i.e. specific functions), demand matrices and results. This approach to organizing data increases the degree of consistency of the data base while the user works on, and eventually compares, several alternatives to the case in hand.

Finally, the data base also contains, besides some auxiliary information such as geographical lines, the "results" of assigning the demand to the available services: service frequencies and freight flows for all markets. These results may either come from an application of an optimization or simulation procedure, or represent the actual operation of the system for a given period (this is useful for analysis and comparison purposes).

It is worth mentioning that all these data are stored in a data base which is local to the DSS and therefore distinct from the MIS. This arrangement is needed since the data available through the MIS may be significantly larger than what is required for a particular set of tactical or strategic analyses. Moreover, the efficient storage format for the whole of the company's data generally is quite different from that required by a specific DSS. The choice of a local data base implies, however, that special procedures, "filters", have to be written in order to insure the transfer of data between the company's MIS and the DSS. However, as no two MIS have the same content nor format, those filters will have to be custom designed for each application.

One should also note that an important characteristic of the network tactical planning problem is the path structure of most of the elements that make up the transportation system, in particular the services and the traffic flows, as well as their hierarchical relationships. The organization of the local data base should reflect this characteristic and aim to facilitate the requirements of both the optimization procedures and the interactive-graphic interfaces. While commercial data bases offer several interesting features, they are not designed to efficiently process the kind of requests needed for tactical planning. For this reason we have designed a proprietary data base, which has the additional advantage of portability, as well as that of facilitating the maintenance of the DSS.

The last issue we would like to discuss regarding the data requirements concerns the possible data sources. The description of the physical network may, for example, be imported from the MIS by using the above-mentioned filters. The spatial coordinates of the nodes (i.e. the geographical representation of the network) may either be obtained from several public or private agencies, or it may be entered by using special input devices like a digital plotter or a graphic tablet. Furthermore, nodes and links could be added, deleted, or modified, by using an interactive-graphic editor provided by TACTIC. This editor may also be used to modify an already existing network to adapt it to the current scenario. Similarly, the initial service network may be extracted from the MIS, it could be a, eventually interactively modified, copy of a service network already in the local data base, or it may be generated by using an optimization procedure. The other types of data, demand, unit costs, functions, may also be obtained from the company's MIS, or they may be input and interactively, graphically when

appropriate, modified. Note that, evaluation and inference procedures (regression equations, demand forecasting models, etc.) are usually required in order to obtain this last type of data. These procedures are particular to each company, and thus have to be application specific and not part of TACTIC.

3.3 The Interfaces

We have already mentioned the *data* interface between the DSS and the MIS, and the need to customize this aspect of the DSS to insure its efficient integration amongst the planning tools available in each particular company. There is, also, the *batch* interface, which provides TACTIC with the capability to input and output large amounts of data, in prespecified formats. Although important, the development of this type of interface is rather straightforward and does not require additional discussion in the present context.

The *user* interface is a key component of a DSS. It principally provides the user with menus and commands to control the system. It may also greatly contribute toward the success of the system by virtue of its ''user-friendliness''. Indeed, for transportation planning problems, where the output generally consists of essentially ''graphical'' information, the development of user interfaces which are graphic and interactive seems the most natural approach. *User interactive-graphic* interfaces thus allow the user to visualize a large gamut of diverse information: histograms, function evaluations, matrix desire lines, total supplies and demands, etc. Their main objective, however, is to provide the user with the means to access, modify and display data related to the networks under study. Worthy of emphasis are the *modify* capabilities which allow the user to alterate the contents of the data base while manipulating its graphical representation. Also worth noting is the possibility to compare data relative to two different situations (scenarios), and to graphically display the differences. These functionalities, which are also to be found in a few other transportation planning systems, significantly enhance the scenario construction and analysis capabilities of the system.

Note, finally, that the complexity of representing data for network tactical planning problems is increased by the ''path'' structure of most of the transportation system's elements, and by the requirement to display and analyze network components (e.g. a terminal) according to several attributes (e.g. number of trailers loaded/unloaded, total traffic by market, average

delay at cargo doors, etc.). A number of elegant and easy to implement solutions to these problems are suggested in [2].

3.4 Models and Solvers

We terminate this section by outlining the main characteristics of the models and solvers which form the methodological core of our DSS. The mathematical formulation of the model, detailed analyses of its properties, and the algorithms to solve it, may be found in [1] [4] [6] [11] and [13].

The main model offered by TACTIC is a network load plan formulation. The model has the structure of a mixed integer, nonlinear multicommodity multimode flow problem. Integer variables are used for service frequencies, while traffic volumes are represented by continuous variables. The formulation displays a block-diagonal constraint matrix, where each block is a one row matrix corresponding to the flow conservation equation binding the itinerary flows for a given market. This structure is particularly amenable to efficient solution algorithms based on decomposition principles.

The objective function represents the total system cost: traffic and itinerary related costs plus the cost of offering the transportation services. It is a generalized cost, in the sense that both operating and service related costs may be included. It is at the level of this objective function that the relationships and trade-offs among the various system and policy components are considered by the combination of the operating costs and the delays encountered by tractors, trailers and traffic in terminals and on the lines of the network due to congestion and to the operating policies. Among the most frequently encountered terms in the objective function are: the cost of handling freight in terminals, the transportation cost of a (empty or loaded) trailer, the average (and its associated variance) freight consolidation delay at terminals, the trailer loading/unloading time, the mean transportation time, etc. Delays may either be directly incorporated into the objective function, via user-defined unit time costs for vehicles and freight, or could be used to compute service penalties with respect to the user-defined service targets for each (or for selected) markets. Both approaches may be jointly used, when appropriate.

The important point which has to be made concerning this model is that it is not a rigid formulation into which the user is expected to squeeze his problem, but rather a flexible modeling framework which may be tailored to the requirements of each motor-carrier and each particular scenario. Furthermore, the user may in most cases perform himself this adaptation, without the express need to call on the help of an operations research or computer science specialist. The capability to adjust to a particular situation comes from the intrinsic nature of the model, where the operational and economic characteristics of the transportation system are synthesized into the path structure of the services and itineraries and into the various functions, and from the very mild assumptions on these functions which are required by the solution method.

Hence, TACTIC also offers tools to define and modify the model of the operation of LTL motor-carrier transportation systems, as well as the precise method of analysis and resolution of the resulting problems. In particular, the user may either choose from a wide gamut of terminal and line-haul cost and delay functions, or may, totally or partially, specify his own. Algorithmically, the first case is the most efficient, since the appropriate elements needed for the resolution of the problem (e.g. function derivatives) are then already determined and programmed into the system. We plan to systematically maintain and update this list.

The algorithm provided by TACTIC to solve this model parallels its flexibility and adaptability. It is based on decomposition, column generation, shortest paths computation and "steepest descent" techniques. These procedures are grouped into several algorithmic units that may be invoked either as a complete algorithm to solve a given problem, or individually to perform specific tasks, such as the evaluation of the system (generalized) cost of a given set of results, the determination of the best traffic distribution given a set of services and frequencies, the search for alternate solutions, the post-optimal evaluation of new services, etc.

IV. CONCLUSIONS

For several years now, we have used the methodology briefly described in Section 3.4 to analyze and help solve network tactical planning problems in a variety of contexts including rail [3], [6], LTL motor-carrier transportation [11], [13] and postal services [14]. We have also developed models, methodologies and computer-based planning systems for a number of other transportation problems.

One of the main conclusions which may be drawn from all these studies is that the complexity of the problem requires a high degree of methodological sophistication in the models and methods used to solve them. Besides, their sophistication not withstanding, no model can include all the unwritten rules and traditions which are part of a company's folklore and operations usage and, thus, a strong system-user interaction is required. Then, if these models and methods are delivered *per se*, not only the training requirements are excessively long, but the initial (and even later) reaction of the potential users may be rather negative. They may have the impression that they do not control the system or, worse, that one attempts to replace them with a machine, thereby, increasing the risk of failure. On the other hand, when sound methodology is at the core of a comprehensive DSS which, through its interactive-graphic capabilities, lets the user control the process, sophisticated models and methods are accepted and become part of the planning process of the company or agency.

We have presented such a DSS for the tactical network planning of intercity multimodal multicommodity freight carriers. It takes advantage of the latest technological developments, while providing flexible and powerful modeling capabilities which allow it to adapt to a large variety of situations.

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